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Analysis of the GPS Observations of the Site Survey at Sheshan 25-m Radio Telescope in August 2008

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Abstract

The processing of the GPS observations of the site survey at Sheshan 25-m radio telescope in August 2008 is reported. Because each session in this survey is only about six hours, not allowing the subdaily high frequency variations in the station coordinates to be reasonably smoothed, and because there are serious cycle slips in the observations and a large volume of data would be rejected during the software automatic adjustment of slips, the ordinary solution settings of GAMIT needed to be adjusted by loosening the constraints in the *a priori* coordinates to 10 m, adopting the “quick” mode in the solution iteration, and combining Cview manual operation with GAMIT automatic fixing of cycle slips. The resulting coordinates of the local control polygon in ITRF2005 are then compared with conventional geodetic results. Due to large rotations and translations in the two sets of coordinates (geocentric versus quasi-topocentric), the seven transformation parameters cannot be solved for directly. With various trial solutions it is shown that with a partial pre-removal of the large parameters, high precision transformation parameters can be obtained with post-fit residuals at the millimeter level. This analysis is necessary to prepare the follow-on site and transformation survey of the VLBI and SLR telescopes at Sheshan.

1. Introduction

The reference point of a station may change due to maintenance of equipment, replacement of devices, earthquakes, or various other reasons, which may lead to uncertainties in the study of geophysical phenomena or the position determination of targets. Therefore, it has been proposed to conduct site surveys at the reference stations of the ITRF once or twice per year and to conduct additional surveys when there are fundamental repairs of the station or when unexpected events occur that necessitate the monitoring and tracing of possible changes of the reference point. Local surveys at co-location sites are especially proposed to determine the three-dimensional (3D) coordinate difference vector of reference points, which can be used as a constraint in the combination analysis of terrestrial reference frames and in the analysis of possible systematic errors between various space geodetic techniques.

The VLBI, SLR, and GPS techniques have been co-located at Sheshan station of Shanghai Astronomical Observatory for more than a decade; but Sheshan has lacked for many years any high precision local tie parameters. In 2001, the International Earth Rotation and Reference Systems Service (IERS) reported that the local tie parameters between VLBI and SLR at Sheshan were in error in the three components by 2.4, 1.3, and 1.9 cm, respectively [1]. In November 2003 the IERS organized an international expert team to survey at Sheshan [2]. The SLR equipment however was moved to its present new location in 2005, and in 2007 the VLBI antenna underwent track foundation repair and wheel bearing replacement. Therefore the tie parameters at Sheshan needed to be re-determined; this includes a survey of the SLR telescope and the 25-m VLBI antenna as well as a transformation survey between the two sites.

The 25-m radio antenna at Sheshan has an alt-azimuth mount; the vertical axis is firmly connected to the foundation. The reference point usually is considered to be the intersection of the vertical axis with the plane containing the horizontal axis. If the two axes do not intersect, then the distance between the two axes is the axis offset, which will cause systematic errors at different orientations of the antenna. To do a local survey of the antenna is to determine the 3D geocentric coordinates of the reference point, plus a possible axis offset. Such a survey is an important part of the work to get the local tie parameters among the co-located space geodetic techniques at Sheshan.

In order to monitor a possible change of the reference point of a station in ITRF, the coordinates of the reference point in the local control polygon is usually determined by a conventional geodetic survey, the ITRF coordinates of the control points in the polygon are usually determined by a GPS survey, and through coordinate transformation between the local and ITRF coordinates of the control polygon, the coordinates of the reference point in the ITRF are obtained. So the precision of the local tie parameters is closely related to the reduction precision of the GPS observations and the precision of the transformation parameters between the GPS measurements and the conventional geodetic measurements. In this report the GPS observations of the August 2008 site survey at the Sheshan 25-m antenna are processed, and the transformation parameters to the conventional geodetic measurements are determined. This constitutes a necessary preparation for the follow-on site survey and local tie survey of VLBI and SLR at Sheshan.

2. The GPS Survey of the Local Control Polygon and Data Analysis

The local control polygon (LCP) for the survey of the Sheshan 25-m antenna is shown in Figure 1. Points 1 through 5 are reinforced concrete pillars with a stainless steel plate on top bearing a forced centering screw; the design is according to reference [3]. The reference points of the pillars are on the upper surface of the plate and in the center of the screw. All the points are directly visible from each other, except for the view between points 2 and 3 which is obstructed by the antenna control room. In Figure 1 the relative location of the IGS fiducial station, SHAO, is labeled by “GPS”. Equal precision GPS surveys were performed on all baselines between points 1 through 5 using Topcon Legend-C receivers at a sampling interval of 5 s, cut-off elevation angle of 10° , and using static processing mode. Each session lasted about six hours, and there are 12 sessions in total.

2.1. GPS Data Processing

Currently the most commonly used processing softwares for GPS observations include GAMIT, Bernese, and GIPSY. With precise satellite ephemerides and precisely known coordinates of the reference stations, the determination precision for a baseline is up to 10^{-9} by GAMIT, which has open source code and can be modified by users. Since we used single frequency GPS receivers in our survey, SHAO, which is less than 150 m from the local control points, can be taken as the reference station with precisely known coordinates in ITRF. With double difference solution mode in GAMIT the effects of error sources such as the satellite orbit uncertainty, clock bias, and ionosphere and troposphere delays on the solution can be mitigated.

The ordinary settings for processing GPS observations in GAMIT are to apply strong constraints to the *a priori* coordinates of the reference station, for instance 5 mm in the horizontal

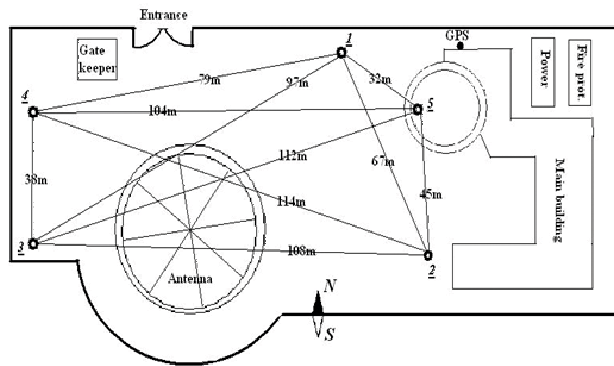


Figure 1. The local control polygon at the site of the Sheshan 25-m antenna.

direction and 5 cm in the vertical, as well as automatic correction of cycle slips and solution iteration. We take session 2008.237X as an example, which includes points 1, 4, and SHAO in Figure 1. From Table 1 it is clear that with the ordinary settings of GAMIT there are only about several hundreds of double difference observations, which are rather below the ordinary data level of several thousands collected within six hours by three stations of very short baselines. The formal errors of the baseline vectors are too large, up to one meter, so the solution is unsuccessful. A similar situation occurs when processing other sessions in this survey with the ordinary settings of GAMIT. For some cases the formal errors of baseline vectors are relatively small but the postfit normalized root mean square (*nrms*) of residuals is too large, which also indicates an unsuccessful solution. In a closer look, we found that there are too many cycle slips in the GPS observations of the survey. The automatic correction of cycle clips by GAMIT usually causes the whole path of a satellite to be deleted. In this report some adjustment to the ordinary solution settings of GAMIT are adopted as follows.

- Taking into account that each session is only about 6 hours, which is inadequate to smooth out the subdaily high frequency variations due to solid earth tide, ocean loading, and so on. If strong constraints were applied to the coordinates of the reference station SHAO, the high frequency variations would seriously affect the determination precision of the unknowns. Concerning the ultra-short baselines of about 100 m in length in our survey, the variation of coordinates of the two ends of the baseline caused by tidal effects could be treated as synchronous and in the same direction. So in our analysis a loose constraint of 10 m is applied to the *a priori* coordinates of all the stations, and the baseline solution mode is adopted.
- During the data processing with GAMIT, the data files of orbit and station coordinates (L and T file) are updated, and the “Quick” iteration mode is adopted. The ambiguity is not solved for in order to avoid deleting too much data. After the quick intermediate solution, the interactive editing software Cview is used to manually repair cycle clips until the data series becomes smoothed.
- The batch file is modified to let GAMIT read the data file (C file) resulting from the manual repair of the cycle slips and perform the follow-on automatic correction of the slips and

solution iterations.

- The previous two steps are repeated until the observation series becomes smooth and the postfit residuals are normally distributed.

Comparing the results of the adjusted and ordinary settings of GAMIT, Table 1 shows that after the adjustment the number of double difference observations has significantly increased and is on a relatively reasonable level. The *nrms* is usually taken as a checking standard for the quality of a single-session solution, whose value is theoretically 1 and is 0.25 by experience. After the adjustment to the solution settings all the resulting *nrms* of the baseline vectors of the GPS survey sessions are smaller than 0.5, and the formal errors of the baseline vectors are on the millimeter level. So the adjustment to GAMIT ordinary solution settings is effective.

Table 1. A comparison between the ordinary and adjusted settings of GAMIT.

Baseline	ordinary	adjusted
1_4	79.6089±0.0040 m	79.6081±0.0017 m
1_SHAO	36.3658±0.6393 m	36.6668±0.0019 m
4_SHAO	113.6863±0.6508 m	114.0645±0.0021 m
Observations	525	3916
Prefit <i>nrms</i>	89.99	44.34
postfit <i>nrms</i>	0.19	0.22

2.2. The Coordinates of the Control Polygon in the ITRF2005 System

Since the GPS survey of the polygon only lasted about five days, the variations of the coordinates of control points in the polygon due to plate motion could be neglected on the millimeter level; the mean epoch of the survey is adopted as the reference epoch, which is MJD54702.5. At this epoch the coordinates and velocities of SHAO in the ITRF2005 frame are theoretically deduced and taken as reference. Then those of the polygon deduced from the solutions of baseline vectors from GAMIT are taken as *a priori* values of unknowns. Through spatial error compensation software GPS_net [4], the results are shown in Table 2, from which it is clear that the coordinate precision of all the points in the polygon is better than 2 mm.

Table 2. The coordinates of the control points in ITRF2005.

Station	X/m	Y/m	Z/m	$\delta X/m$	$\delta Y/m$	$\delta Z/m$
1	2831698.7023	4675677.0289	3275367.9915	0.0018	0.0018	0.0018
2	2831741.6347	4675686.7828	3275317.0931	0.0018	0.0018	0.0018
3	2831649.2418	4675743.1305	3275316.8390	0.0018	0.0018	0.0018
4	2831638.7847	4675726.2489	3275349.9700	0.0018	0.0018	0.0018
5	2831729.4385	4675675.8735	3275359.0483	0.0019	0.0019	0.0019

2.3. Transformation Between GPS and Conventional Geodetic Surveys

A conventional geodetic survey to the LCP was completed by total stations. Point 1 was taken as the origin of the local frame and point 2 as the reference direction ($y = 0$). The local frame is right-handed, and the coordinates of all control points resulted from a 3D error compensation of the conventional geodetic observations [5]. In order to determine the transformation relationship from the local frame to the GPS survey and to check the GPS data processing, a seven-parameter transformation was solved for. The local frame is a quasi-topocentric one at point 1 (SEU), while that in Table 2 is a geocentric right-handed frame, so there are a large translation in the magnitude of the Earth's radius and a large orientation difference, which possibly obstruct the high precision determination of the transformation parameters. Various trial solutions are performed to solve for the seven transformation parameters with a dynamic range for the *a priori* values of unknowns from 0.01 to 1000. Tests show that it is helpful to partly remove the large translations and rotations before the parameter fitting. The postfit residuals are less than 5 mm, and the seven parameters are as follows.

$$\vec{T} = \begin{bmatrix} -2831698.701 \pm 0.0011 \\ 4675677.029 \pm 0.0012 \\ 3275367.989 \pm 0.0011 \end{bmatrix} m, \quad D = (-6.70 \pm 1.50) \times 10^{-5}, \quad \vec{R} = \begin{bmatrix} 55291.1 \pm 6.1 \\ -67161.1 \pm 4.7 \\ -62009.9 \pm 3.5 \end{bmatrix} as$$

3. Conclusions

The GPS observations in the site survey at the Sheshan 25-m antenna in 2008 were processed with GAMIT, Cview, and GPS_net. Due to serious cycle slips in the GPS observations, some adjustments are adopted to the ordinary solution settings of GAMIT. In the determination of the seven transformation parameters from the conventional geodetic survey to the GPS survey, because large rotations and large translations may leave unfavorable effects on the parameters, several trial solutions are made and compared, which show that a pre-treatment of the large rotations and translations is necessary in order to precisely determine the parameters. The analysis in this report is a necessary preparation for the follow-on site survey and local tie survey of VLBI and SLR at Sheshan.

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